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A3. SPACE EXPLORATION SYMPOSIUM
2B. Moon Exploration - Part 2

LUVMI: an innovative payload for the sampling of volatiles at the Lunar poles

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Abstract

The International Space Exploration Coordination Group (ISECG) identifies one of the first exploration steps as in situ investigations of moon or asteroids. Europe is developing payload concepts for drilling and sample analysis, a contribution to a 250kg rover as well as for sample return. To achieve these missions, ESA depends on international partnerships.

Such important missions will be seldom, expensive and the drill/sample site selected will be based on observations from orbit not calibrated with ground truth data. Many of the international science communitys objectives can be met at lower cost, or the chances of mission success improved and the quality of the science increased by making use of an innovative, low mass, mobile robotic payload following the Lunar Exploration Analysis Group (LEAG) recommendations.

The LUnar Volatiles Mobile Instrumentation (LUVMI) provides a smart, low mass, innovative, modular mobile payload comprising surface and subsurface sensing with an in-situ sampling technology capable of depth-resolved extraction of volatiles, combined with a volatiles analyser (mass spectrometer) capable of identifying the chemical composition of the most important volatiles. This will allow LUVMI to: traverse the lunar surface prospecting for volatiles; sample subsurface up to a depth of 10 cm (with a goal of 20 cm); extract water and other loosely bound volatiles; identify the chemical species extracted; access and sample permanently shadowed regions (PSR).

These payload characteristics of LUVMI will permit to maximize sample transfer efficiency and minimize sample handling as well its attendant mass requirements and risk of sample alterations. By building on national, EC and ESA funded research and developments, this project will develop to TRL6 instruments that together form a smart modular mobile payload that could be flight ready in 2020.

The LUVMI sampling instrument will be tested in a highly representative environment including thermal, vacuum and regolith simulant and the integrated payload demonstrated in a representative environment.

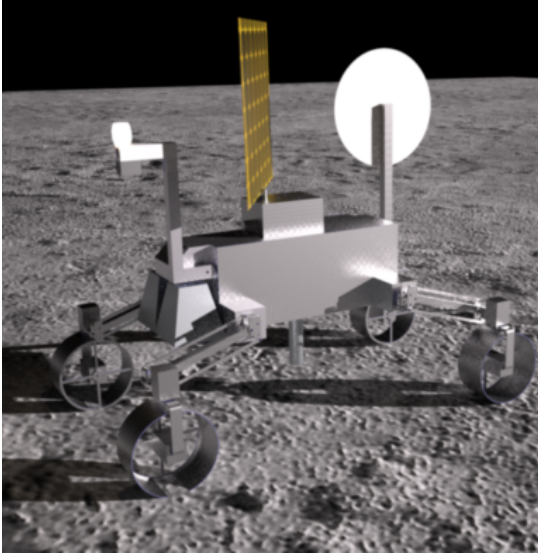


Figure 1: The LUNar Volatiles Mobile Instrumentation rover (LUVMI) - preliminary artist's concept

1. Introduction

Future long-term lunar exploration efforts will rely heavily on in-situ resource utilization to produce mission consumables, fuel or even structures on the lunar surface, thus reducing transportation costs. One of the most interesting resources available at the Moon are loosely bound (physisorbed) volatiles found in or around cold traps near the lunar poles, such as water, nitrogen, and carbon dioxide.

A resource like water, delivered to a depot in cis-lunar space, could be used by commercial spacecraft going to geosynchronous orbits and make Mars missions more affordable, by taking advantage of the reduced gravity well of the Moon. Another challenge that volatiles could address is related to the more than 700 kg [1] of volatiles that are required to sustain a single person during a year on the Moon, on orbital stations, or even the portion necessary for Mars transfer; which could be obtained directly from the Moon surface. Additional applications include plastics for fabrication on the Moon, which can be obtained from the hydrogen and carbon.

Recent years have seen several remote observation missions that have particularly searched for evidence of lunar water. Clementine [2] and Chandrayaan-1 [3] have performed radio-wave reflection measurements, with results consistent with the presence of water. Other orbital measurements, including the LOLA laser altimeter of LRO [4] and measurements of epithermal neutron emissions [5] have yielded inconclusive results that suggest water may be present but does not necessarily coincide with Permanently Shadowed Regions (PSRs). So far the only direct observation of lunar water was performed during the LCROSS experiment, when the ejecta plume of an im-

pactor in the Cabeus Crater of the lunar south pole was observed and a water content of 5.6 ± 2.9 wt% was detected [6].

The next logical step in lunar volatiles exploration is the in-situ investigation around or even inside a PSR, which will provide a definite answer to the question of the existence of lunar water and provide ground truth data for the calibration of orbital measurements.

1.1. LUVMI and the ISECG Objectives

LUNar Volatiles Mobile Instrumentation - LUVMI (see Figure 1), addresses top priorities established [7] by the Lunar Exploration Analysis Group (LEAG) Volatiles Specific Action Team (VSAT). These are:

1. Determining the variability of volatile distribution
2. Identification of the chemical phase of volatile elements
3. Analysis of physical and chemical behaviour of lunar soil with temperature
4. Determining geotechnical properties
5. Determining current volatile flux

The LEAG VSAT concluded that a mobile payload with capability to access depth of 20cm would properly address 4 priorities, while partially addressing the 2nd one. Only a drilling capability with depth exceeding 1 m fully meets the 5 priorities, but this comes at a high cost in terms of mass, energy and time. LUVMI provides a smart, low mass, innovative, modular mobile payload comprising surface and subsurface sensing with an in-situ sampling technology capable of depth-resolved extraction of volatiles, combined with a volatiles analyser (mass spectrometer) capable of identifying the chemical composition of the most important volatiles; LUVMI aims to develop a 20cm-deep sampling capability, therefore addressing the biggest share of these LEAG VSAT priorities.

1.2. Flight Opportunities

The LUVMI system is designed to fly as a secondary payload on one or several missions planned to land on the Moon. In principle it can be delivered either as a single payload or as a piggy-back payload accompanying a major, primary payload; or as a group of multiple LUVMI payloads on the same lander.

No particular mission is targeted yet. The technical concept has been conceived such that it is compatible with at least 80% of the currently intended or planned missions, thereby providing sufficient flexibility to identify and down-select one or several flights as opportunities become available.

To this end a survey of currently planned missions from various countries was performed, together with interaction with commercial landing service providers. The information was used to build an envelope of main technical requirements (maximum dimensions, mass limit, etc.) that would allow to accommodate LUVMI on most of those landers. This approach provides sufficient confidence and margin to be able to fit LUVMI also on new flight opportunities in the future, that are not on the map yet. The list of missions used to build this enveloping requirements includes:

- Chang'e 6 of China
- Luna-25, -27, -28, and -29 of Russia
- NASA Resource Prospector
- Peregrine lander, commercial lander led by Astrobotic (US)

In addition to the above opportunities the Canadian Space Agency (CSA) is studying a lunar rover, the Japanese Aerospace Exploration Agency (JAXA) is studying a lunar lander, ESA is considering contributions to a joint Lunar Polar Sample Return mission, and the Korean Aerospace Research Institute (KARI) is studying lunar surface payloads for launch at some future time.

A common criterion for potential host lander missions is a landing at preferably more than 80 degrees latitude of the Moon, in order to get the instrument package as close to the areas of interest as possible. Once landed and deployed, the LUVMI system will operate independently from the lander and its primary payload both in terms of power and communications. The landing site is intended to be, at this stage, in an illuminated area close to PSRs. The PSRs in proximity should be hidden from the sun, but not from Earth.

2. Mission, Operations and Requirements

2.1. Mission Baseline and Scientific Objectives

The primary scientific objectives of LUVMI are to (a) detect and roughly quantify the abundance of loosely bound volatiles over a range of locations in the lunar polar regions and in the shallow subsurface, (b) identify the chemical phase of detected volatiles, (c) investigate the migration of volatiles over the lunar surface, and (d) determine relevant engineering properties of the lunar regolith in the polar regions. The primarily targeted volatile component is water.

LUVMI shall be able to distinguish between free water (ice frozen into / onto the regolith) and water which is chemically bound in the mineral phase. In addition to water, the specific volatiles observed in the LCROSS Cabeus crater plume shall also be targeted: H₂S, NH₃,

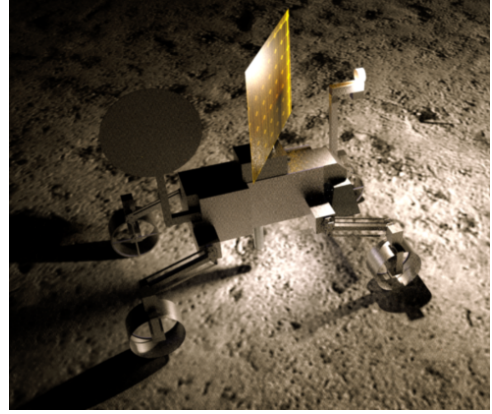


Figure 2: LUVMI operating in shadowed region - artist's concept

SO₂, C₂H₄, CO₂, CH₃OH, CH₄. LUVMI is intended as a possible secondary payload to a lunar landing mission. Preliminary requirements for the landing site are:

- Solar illumination >40 % of lunar day/night cycle
- Distance between landing site and PSR <1 km
- Earth visibility >40 % of lunar day/night cycle
- No major obstacles in 250 m radius

Several locations of interest have been characterised for the operation of LUVMI in terms of their scientific potential:

- Vicinity of the landing site: Measurement of possible volatile species and contamination from the lander exhaust with depth profiles within 10 m of the landing site.
- PSR: At least three depth profiles of volatiles shall allow a spatial and depth resolution of volatiles in PSR. The latter are defined as areas with no solar illumination at latitudes >80, with surface temperatures >100 K, and where supportive remote sensing data suggests enhanced water/hydrogen concentration.
- Vicinity of PSR: Depth measurements shall be performed in defined distances from the PSR boundary to characterise the impact of gardening processes on the distribution of volatiles.
- Location with regular illumination: The abundance of volatiles near the lunar poles, at sites with an illumination of 10% to 70% of the lunar day/night cycle shall be measured to help the understanding of their accumulation processes.
- Non-permanent shadow behind small obstacle/boulder: Depth profiles shall be taken in illuminated areas as well as nearby non-permanently shadowed areas to assess the accumulation of volatiles in colder areas over time and space.

- Night to day termination event: The release of volatiles during a transition from night to day shall be measured at locations with particularly sharp transitions, e.g. slopes.

2.2. Concept of Operations

The initial surface operation planning is driven by finding the best compromise between engineering constraints (power, range, speed) and science goals (number of individual samples), though it may evolve as information on landing site options are considered. The main operations to be performed on the surface include the following:

- Post landing check-out
- Rover egress
- Landing site survey
- Wide field area survey / prospecting (volatile “hot-spots”)
- Terminator passage
- PSR sampling

The baseline operations assume a short 14 day mission lifetime and are not assuming any particular landing site. The baseline operations consider a notional location with a number of nearby PSRs (approx. 1 to 2 km from the landing site). In this scenario, the key objectives would be to conduct operations in an increasing order of risk to allow science measurement to be obtained at an earliest opportunity prior to performing operations that may pose a risk to the rover, such as egress into shadow, egress into PSR and drilling into the regolith.

Before leaving the landing platform, the state of the rover is determined by performing a systems check for each instrument. The rover will then drive onto the lunar surface, during which background measurements will be made by the Surface Imager instruments and Volatiles Analyser (VA), in order to investigate how the thermal and mechanical inputs to the regolith caused by the motion of the lander affects volatile release.

An understanding of the nature and extent of contamination and alteration of the lunar surface resulting from the action of the landers motors during descent will be of great importance to follow on missions and in particular those without a mobile element. In these follow-on missions, where it is likely that the Landers robotic arm will not be able to access uncontaminated regolith, an understanding of the distribution of contamination and empirical data on how the volatiles evolve with time is a high priority. An early conducted landing site survey will target (i) determination of the volatiles content as a function of lateral distance from Lander to investigate decline in alteration with distance and (ii) measurement of the volatiles

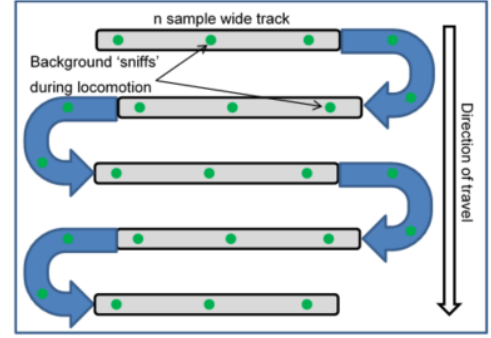


Figure 3: Raster-type sampling strategy for performing a wide area survey for volatile-rich hot spots

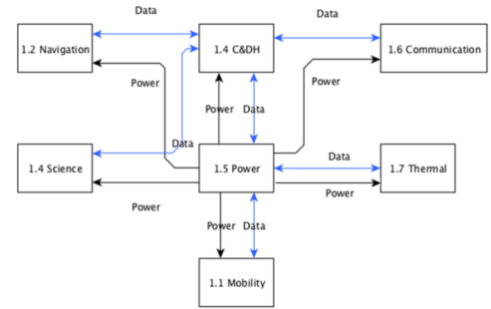


Figure 4: LUVMI reference high level physical architecture (data and power interfaces)

as a function of depth which will address the penetration of volatiles. If there is a rock or boulder in the vicinity, another test will be performed to study how it shields the surface from contamination.

If a suitable location is found that has an illuminated region and an area which has temporary shadow, such as behind a rock, a series of measurements will be made using the Volatiles Analyser (VA) and Volatiles Sampler (VS) to investigate the variation in the volatiles content at both a spatial and temporal level.

To conduct a wide area analysis and prospect for volatile-rich hot spots, LUVMI will traverse a large area and conduct a number of rapid measurements as it travels, shown in Figure 3. Background measurements will map volatiles liberated by illumination and/or mechanical perturbations. When detecting a volatile-rich area, LUVMI will cease traverse and conduct a number of vertical survey measurements. LUVMI will also be directed to PSRs to perform additional surveys.

2.3. Preliminary Architecture

The LUVMI reference architecture encompasses a total of 7 subsystems (see Figure 4), addressing the functions established by the Science Requirements and the Concept of Operations that were produced earlier in the project.

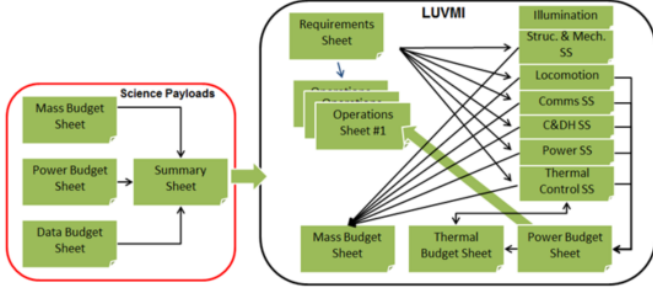


Figure 5: LUVMI parametric model spreadsheets (based on ESA APPS)

A trade-off analysis of the different options and characteristics for the subsystems was done based on this breakdown, to obtain a baseline architecture. Associated to this, a parametric model was developed to simulate the impact of different assumptions and configurations. Related topics include system engineering budgets (mass, power, data and processing, thermal, RF link), mission operation modes and power consumption, timeline of operations (taking into account e.g. illumination), as well as sub-systems specification and design considerations.

The parametric model is an adaptation of the ESA APPS (Autonomous Planetary Payload System) [8] model to rover considerations (locomotion sheets added) as seen in Figure 5.

The following sections focus on the science subsystem (in particular the volatiles sampling and analysis instruments), and the rover platform. These considerations refer to the baseline flight rover. A study is currently planned with the European Space Agency that includes the assessment on how low-temperature battery-less architectures and technologies could enhance LUVMI.

3. Science subsystem

3.1. Volatiles Sampler

The Volatiles Sampler (VS) is a novel mission-enabling instrument that combines drill, sample handling and preparation and gas extraction in a small and compact unit. The concept is shown in Figure 6: A central heating element and the surrounding drill shell are inserted up to 20 cm into the regolith. The heating rod then heats the enclosed regolith sample to release any bound volatiles. While some of the released volatiles are lost through the open bottom of the shell, around 50% (Parzinger 2013) are able to pass through the measurement orifice at the top of the instrument and into the Volatiles Analyser. The orifice allows a rough estimation of the amount of released volatiles, while the Volatiles Analyser (VA) performs a detailed chemical characterisation.

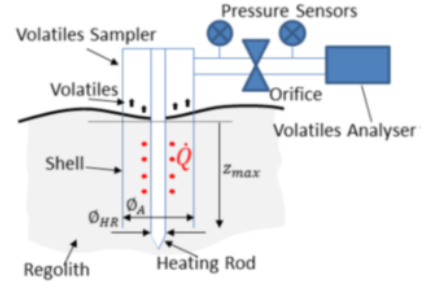


Figure 6: Volatiles Sampler concept

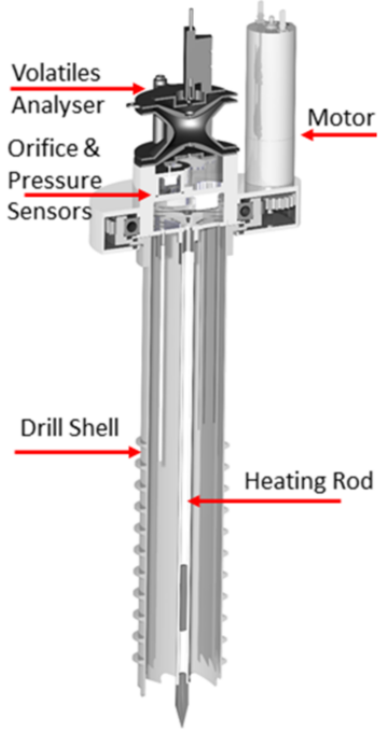


Figure 7: CAD model of the integrated Volatiles Sampler and Volatiles Analyser

Figure 7 shows a CAD section of the VS. It features a rotating drill shell that reduces the necessary vertical force during insertion to less than 30 N. The entire instrument mass is less than 1.5 kg. The rotation of the shell will be provided by the motor, which transmits the torque using a drivetrain. A ball bearing allows a free relative motion between the static and the dynamic part. To avoid any leak of volatiles and a penetration of lunar dust into the mechanism, sealings are interposed between the moving parts to fix the interstices and ensure the function of the mechanism. The shell will be provided with a system that removes the internal remaining soil avoiding the contamination of later samplings. To allow a proper penetration, the rotation rate is synchronized with the insertion speed according to the pitch of the thread, granting a proper sampling.

3.2. Volatiles Analyser

The Volatiles Analyser (VA) is a mission-enabling element using the principles of mass spectrometry. Mass spectrometry is often referred to as the gold standard technique in terrestrial laboratories for the determination of the elemental, isotopic and molecular composition of sample material. Mass spectrometers form the integral parts of many spacecraft payloads such as the ultra-light (Ptolemy) and static vacuum (Beagle 2 GAP) mass spectrometer based instrumentation designed for in situ geochemical analysis. Ptolemy, an ion trap based gas-chromatograph isotope ratio mass spectrometer on-board the Rosetta Lander [9] [10] returned the first measurements of organic material from the surface (and near surface) of comet Churyumov-Gerasimenko in November 2015.

GAP, a magnetic sector mass spectrometer on-board the Beagle 2 lander [11] was the instrument aimed at performing in situ surface, subsurface measurements on Mars. For the Moon, current data are mostly limited to inferences from orbital data sets which are equivocal and at poor spatial and depth resolution. In addition the LRO spacecraft observed the impact of a spent Centaur rocket stage into Cabeus crater and inferred the presence of a few percent water ice but again data are not conclusive.

The UK-led MoonLite mission [12] proposed the use of a high speed penetrator deployment system to deliver a mass spectrometer instrument which would measure and characterise the volatile content at the penetrator impact site. Unfortunately the MoonLite mission did not progress beyond the study phase and the mission is no longer in planning.

The mass spectrometer selected for the LUVMI Volatiles Analyser is an ion trap mass spectrometer instrument based on the Ptolemy flight-proven instrument (Figure 8) and the MoonLite penetrator deployable instrument. The VA will address the scientific objective of identification and quantification of the volatiles contained in the lunar regolith, at a number of regions near the lunar pole. The ion trap device offers a mechanically simple, low mass, volumetrically compact instrument that is capable of rapid detection of masses in the range of m/z 10 to 150 to extremely low detection levels making it ideal for detection of water and other volatiles that may be liberated from the lunar regolith by LUVMI. In combination with the Volatiles Sampler (Figure 7), these measurements will be made as a function of depth. The ion trap mass spectrometer consists of a number of discrete subsections, these being:

- The ion source, consists of an electron source which ionises the sample gas(s) via electron bombardment. In the Ptolemy instrument the electron beam is generated by a field effect ion source which uses micro-machined silicon nano tips to provide a low power

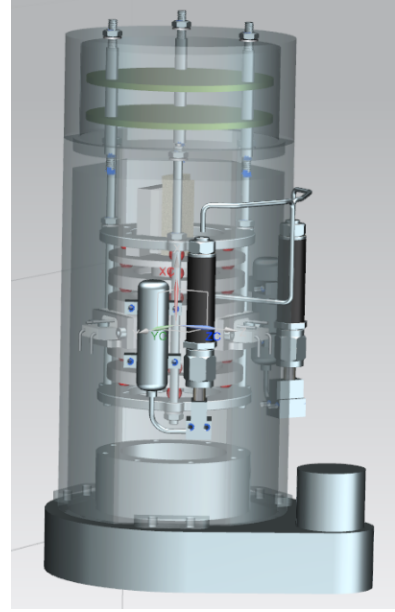


Figure 8: LUVMI mass spectrometer unit consisting of the ion source, mass selector and detector

electron beam. In LUVMI, the VA will use a Carbon Nano Tube electron source [13], that will offer higher emission currents, longer lifetime in a more rugged device.

- The mass selector is formed from three hyperbolic electrodes that form an electro potential region within their structure. By manipulation of the amplitude and/or frequency of the potential on the hyperbolic electrodes ions can be trapped or manipulated to eject them in order of their mass-to-charge ratio.
- The detector, which consists of an electron multiplier that detects individual ions as they leave the mass selector and through a process of amplification multiplies this extremely low current associated with single ions into signals that can be measured by the control electronics.

In addition to the VA mass spectrometer instrument, a reference gas system that store gases for in-situ calibration and soil permeability measurements will be included. The reference gas system utilises gas valve that has been developed for space flight applications at the Open University. The reference gas element stores gas at high pressure in a miniature pressure volume and allows extremely precise flows of the gas to be delivered to the instrument when required. In situ calibration during operation increases the scientific return of the instrument with regards to characterising the liberated volatiles over an extended time period. The new valve technology offers extremely low leak rate with extremely fast actuation times and low power requirements compared to previous technologies.

To date, water doped (10%) lunar simulant material has been prepared and is being characterised under vacuum (210-5 mbar) and low temperature (<140 C) conditions using the in-house vacuum testing chamber. The aim of these early experiments is to determine how the material behaves under lunar like conditions and to provide a volatile rich test matrix for later mass spectrometer testing and evaluation.

3.3. Ground Penetrating Radar

The Ground Penetrating Radar is a mission-enhancing element, allowing the characterisation of the subsurface before the measurements. This, in order to correlate this data with the volatile measurements and imagery, as well as potentially providing criteria on whether to sample a given site or not. Given its flight heritage, a radar based on the WISDOM (Water Ice Subsurface Deposit Observation on Mars) instrument on Exomars is considered. WISDOM consists of an electronic unit in the WEB, and an antenna unit mounted on the rover, facing down towards the surface.

3.4. Ground Temperature Sensor

The Ground Temperature Sensor (GTS) is a mission-enhancing element. GTS is an INTA/CAB developed payload on NASA Mars Science Laboratory that measures the Martian surface kinematic temperature by integrating the IR energy radiated by the ground, and which is located on the MSL booms. In its MSL implementation, to avoid local temperature effects, the GTS focuses on a large ellipsoidal ground surface area of around 100m², measuring its average temperature.

In its potential implementation for LUVMI, a narrower FOV would be necessary that avoids as much as possible direct vision of the rover. The instrument would be forward-pointing and placed on the mast of the rover in order to remotely measure the temperature of the sampling site at a distance, right before sampling.

3.5. Additional Payloads

LUVMI has the capability to accommodate additional mission-enhancing instruments for scientific use. However there is growing commercial interest in the use of the Moon's resources, and hence also commercial payloads can also be considered to be added to the LUVMI payload suite, as the capabilities of the rover platform can be scaled to the specific requirements of the mission. The prospecting data returned by LUVMI and additional commercial instruments will be of high commercial value for the utilisation of the resources of the Moon.

4. Mobile Platform

The main goal of the mobile platform (namely the rover) is to enable the instrument to make measurements over wide areas, including

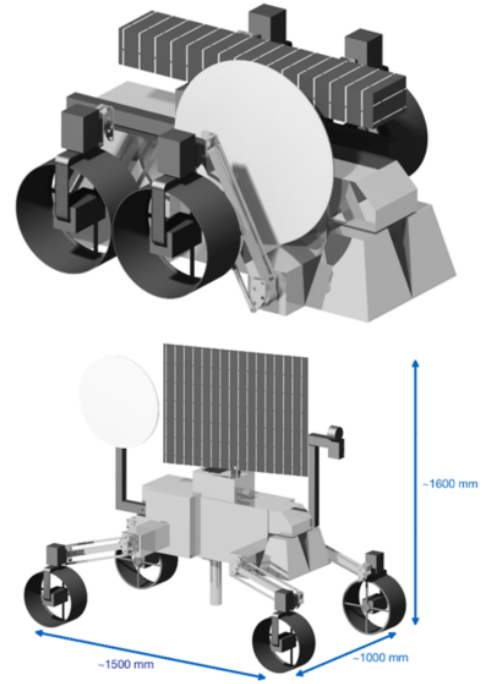


Figure 9: Preliminary CAD of LUVMI rover, in stowed and deployed configurations

- Bringing the LUVMI instruments package to the sampling locations in proximity of, and into PSRs
- Providing electrical power
- Providing thermal management
- Providing Communications and data processing and storage

A preliminary architecture design has been performed. The following are descriptions of different subsystems related to the Platform:

4.1. Mobility

Comprises the core mechanical assembly on which all the other subsystems are installed, and which includes wheels, chassis, motors and an active suspension system. The chassis should support and protect a variety of components, including the instruments, from the harsh lunar environment (dust, radiation, temperature, etc.). Four wheeled legs are used to support and move the rover. Each of them can modify its angle to change chassis/wheel altitude, steer and drive independently. This allows stowing the rover in a compact configuration (see Figure 9), and lowering the chassis when deploying instrument (Figure 10), drilling and sampling regolith in PSRs. A typical survey track for the rover is considered to be 6 kilometers (mission-dependent) comprising slopes of up to 20 degrees.

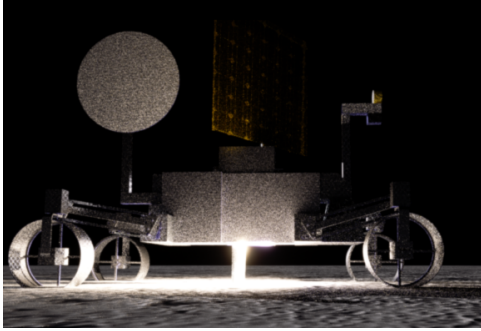


Figure 10: Volatiles sampler in use. The robotic platform is lowered through the use of the active suspension and the sampler is deployed - artist's concept

4.2. Surface imaging instrument

The surface imaging instrument will provide visual information about the rovers environment. Data can be used by either the on-board navigation systems or by teleoperators on Earth. The instrument will also acquire high quality imagery of the surface, mission equipment, and Earth. Additionally, the interaction of the rover and its instruments with the regolith can be visualised.

In line with the compact nature of the LUVMI rover, the power, mass and volume of the instrument will be kept low. The power requirement will be 4W peak for up to two sensors, not including illumination, the volume is expected to be below 50 mm x 50 mm x 200 mm per sensor, and the mass below 400 g per sensor. The instrument will be operational in the temperature range of approximately 240 to 320 K.

An objective of the surface imaging instrument is to use light-field imaging in space. Light-field typically uses a single image sensor, a Micro-Lens Array (MLA) and a main lens. The raw data is a set of sub-images. Using a single exposure an image can be refocused and depth information extracted. The LUVMI surface imaging instrument will be calibrated to allow the construction of 3D terrain maps using a single sensor, without an active focusing mechanism.

The LUVMI camera system will use the latest generation of space-qualified CMOS image sensors. The imaging system will provide ad-hoc functionality. Adjustable frame rates and Regions Of Interest (ROI) will be available to suit the mode of operation, e.g. teleoperations or science imaging. CCDs dominate space imaging and CMOS has little heritage outside of star tracker applications. However, the high number of vendors, low power consumption, ease of integration and potential for radiation hardness make the use of CMOS image sensors attractive.

Development of the LUVMI camera system will require

the miniaturization of light-field technology beyond what is currently commercially available, given the need for a large depth of field and high resolution. A further requirement will be related to the use of MLAs in the space environment. To minimize the mass and volume of the camera systems, fixed camera mounts will be used where possible.

Artificial illumination will be available. The natural lighting from direct sunlight and the Moon albedo is expected to be sufficient during the lunar day, even when operating in some shadowed regions. Artificial illumination will be required in the PSR and in other shadowed regions where the lunar albedo is not sufficient.

4.3. Navigation

Comprises the navigation sensors (IMU, Star tracker/sun sensor, imager, illumination) that are used to perform SLAM (simultaneous localization and mapping) so as to enable a certain level of autonomy, while allowing to return useful information to remote operators for teleoperation purpose. The science subsystem contains the LUVMI instrument package to characterize regolith in PSRs. These are mainly the volatiles sampling and analyzing instruments, a Ground Penetrating Radar (GPR) and a temperature sensor.

4.4. Power

Scientific requirements imply the necessity of making incursions and sampling operations into shadowed areas, both periodically illuminated (e.g. behind boulders) and Permanently Shadowed Regions, and be exposed and operate in termination events. Operations in these conditions are challenging from a power perspective, and require particular energy management considerations.

The assumed time of operation is 14 days, part of it taking place in extreme cold and dark environments. As a baseline, high density batteries are intended for energy storage (e.g. Li-S based batteries), with the use of solar panels for recharging. The use of fuel cells has been considered but preliminarily discarded to benefit the mass and volume budget. Similarly, use of radioisotope generators that would enhance mission duration and permanence in shadowed areas has been considered, however as a baseline, and following the flexibility philosophy of LUVMI, they would not be used in order to make the mission more affordable and less limiting in terms of access to technology.

Using the developed parametric model, the LUVMI team has calculated the power consumption of the rover along a notional path (see Figure 11).

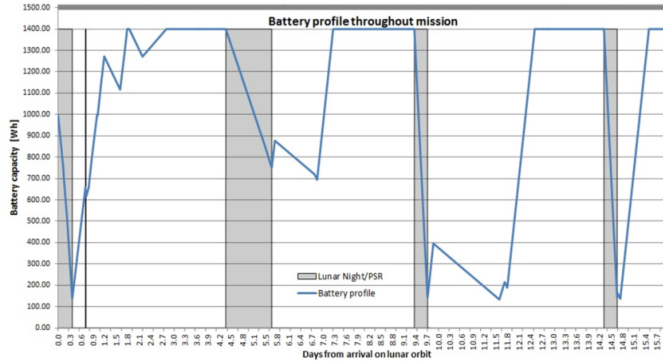


Figure 11: Battery profile along a notional path, including LEOP discharge, a 48-hour hibernation and operations in two PSRs

The incursions in and out of PSRs lead to a charge build-up, thus creating electrostatic discharge (ESD) hazards and possibly an enhancement in dust adhesion. Solutions proposed for this require providing for adequate connection chassis-wheel into the rover electrical grounding [14].

4.5. Command and Data Handling

The baseline design is a Command and Data Handling (CDH) Sub-system composed of:

- Low power consumption processor board (for OBSW), for command and monitoring on-board sub-systems.
- FPGA based image processor board, for processing video and image data and provide information to on-board navigation
- Reconfiguration board, for performing monitoring and reconfiguration of the CDH S/S.
- Providing Communications and data processing and storage Digital I/O board, for general purpose digital interface using CAN I/F SpaceWire board, for receiving high speed data rates from payloads such as on-board camera. Mass memory board (256 Gb), for storing raw and processed data

4.6. Communications

The communication subsystem gathers the components (high gain antenna, dual band transceiver, amplifier, steering mechanism) that are required to establish a reliable communication link to the ground station on Earth (and potentially the lander or orbiter). S-band is to be utilized for low bandwidth data, and X-band for high bandwidth. LUVMI shall be able to benefit from links with the lander or orbiter, if and when available, but this is not mandatory for its operations.

4.7. Thermal Control

There is a need to implement a thermal control strategy guaranteeing at the same time, during daylight, a very high heat rejection capability to reduce overheating of internal and external electronic components, while, during night, a very low heat dissipation to avoid malfunctions due to low temperature.

The need to provide both capabilities becomes challenging in particular because of the very large temperature ranges that can be faced on lunar surface, and especially at low latitude, where the varying sunrays incidence angle brings the diurnal soil temperature up to 400K, while in eclipse this can reach very low values, i.e. 90K. High temperatures can be especially challenging when the rover passes in front of an illuminated boulder. The rover will then be heated by the sun on one side and by the hot boulder and reflected sunlight from the other side.

For what concerns the second aspect relevant to the extreme low temperatures faced during night, they are challenging as they imply the need of heating up the electronic components by continuously providing heat power to keep them above their minimum survival and/or operational temperatures. The strategy for LUVMI involves the use of a hybrid architecture, in which a combination of hardened components, and environmental protection is implemented.

For thermal control, the following passive technologies are envisaged:

- Warm Electronics Box (WEB)
- Multi-Layer Insulation
- Paraffin based Heat Switches
- Flexible Kapton Heaters
- Kapton heaters

5. Conclusion and Future Work

The concept of LUVMI and early work was presented in this paper. After a mission and operation concept definition phase, core technologies are in the process of being developed - the instruments prototypes, targeting a TRL of 6, and the mobility platform (rover) targeting a TRL of 4-5.

A study is currently planned with the European Space Agency that includes the assessment on how low-temperature battery-less architectures and technologies could enhance LUVMI.

LUVMI is expected to result in a viable and affordable mission paradigm for Moon polar science missions, that

should allow establishing by 2020 an innovative participation and funding approach involving non-institutional sources (with a target of 25% of the development costs).

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